Spine

SPINE Volume 47, Number 18, pp 1303–1313


DEFORMITY

# Comparison of Spinopelvic Configuration and Roussouly Alignment Types Between Pediatric and Adult Populations

Yann Philippe Charles, MD, PhD,[a] Vincent Lamas, MD,[a] Brice Ilharreborde, MD, PhD,[b] Benjamin Blondel, MD, PhD,[c] Solène Prost, MD,[c] Eloïse Bauduin, MD,[d] Féthi Laouissat, MD,[e] Guillaume Riouallon, MD,[f] Stéphane Wolff, MD,[f] Vincent Challier, MD,[g] Ibrahim Obeid, MD,[h] Louis Boissière, MD,[h] Emmanuelle Ferrero, MD, PhD,[i] Federico Solla, MD,[j] Jean-Charles Le Huec, MD, PhD,[k] Stéphane Bourret, PhD,[k] Joe Faddoul, MD,[l] Georges N. Abi Lahoud, MD,[l] Vincent Fière, MD,[m] Michiel Vande Kerckhove, MD,[m] Jonathan Lebhar, MD,[n] Hadrien Giorgi, MD,[o] Aymeric Faure, MD,[o] Erik A. Sauleau, MD, PhD,[p] Sébastien Pesenti, MD, PhD,[q] and The French Spine Surgery Society (SFCR)

**Study Design.** Retrospective cross-sectional study.

**Objective.** The aim was to describe spinopelvic alignment types by pelvic incidence (PI) and age to compare the Roussouly classification between pediatric and adult populations.

**Summary of Background Data.** The Roussouly classification was validated for adults. Alignment types may vary during growth.

**Materials and Methods.** Radiographs of 1706 non pathologic individuals (5–49 yr) were analyzed. Individuals ≤19 years were stratified by chronological age and skeletal maturity (triradiate cartilage, Risser), and compared with adults. Global and spinopelvic alignment parameters were assessed. Roussouly Types 1, 2, 3, 3A (anteverted pelvis), and 4 were determined. The distribution of parameters was analyzed by Bayesian inference. The relationship between PI and age by Roussouly type was modeled by linear regression.

**Results.** The Sagittal Vertical Axis C7 decreased during growth and was significantly smaller in adults (20–34 yr) (Pr > 0.99). Thoracic kyphosis and lumbar lordosis increased during growth and were larger in adults (Pr < 0.025). Lordosis increased mainly in the cranial arch (Pr < 0.025). PI and pelvic tilt increased during growth and were larger in adults (Pr < 0.025). In children and adolescents, PI < 45° represented the largest proportion, significantly larger compared with adults (Pr > 0.99). Proportions of Roussouly Types 1 and 2 were similar throughout ages. Types 3 and 4 were rarer during the prepubertal period (Pr < 0.025). The proportion of Type 3A was significantly higher in children and adolescents (Pr > 0.99). Linear regression showed that Type 4 had the largest PI increase with age, with significantly higher curve slope compared with other types (Pr > 0.9999). Types 3, 3A and 2 had similar slopes and lowest PI increase with age.

**Conclusion.** Global and spinopelvic alignment changed during childhood and adolescence, leading to different kyphosis and lordosis distribution compared with adults. Growth-related PI increase influenced Roussouly types with typical predominance of Type 3A in the pediatric population and larger PI increase in Type 4.

From the [a]Service de Chirurgie du Rachis, Hôpitaux Universitaires de Strasbourg, Université de Strasbourg, Strasbourg; [b]Service de Chirurgie Orthopédique Pédiatrique, AP-HP, CHU Robert Debré, Paris; [i]Service de Chirurgie Orthopédique de la Colonne Vertébrale, AP-HP, Hôpital Européen Georges-Pompidou, Université de Paris; [c]Unité de Chirurgie Rachidienne, Marseille; [q]Service d'Orthopédie Pédiatrique, CHU Timone, Aix-Marseille Université, Marseille; [d]Service de Chirurgie Orthopédique et Traumatologie, Hôpital Maison Blanche, CHU de Reims, Reims; [e]Hôpital Privé de l'Est Lyonnais, Saint-Priest; [f]Service de Chirurgie Orthopédique et Traumatolgique, Groupe Hospitalier Paris Saint Joseph; [l]Institut de la Colonne Vertébrale et des Neurosciences, Centre Médico-Chirurgical Bizet, Paris; [g]Hôpital Privé du Dos Francheville, Périgueux; [h]Clinique du Dos Jean Villar, Bruges; [j]Service d'Orthopédie Pédiatrique, Fondation Lenval, Nice; [k]Polyclinique Bordeaux Nord Aquitaine, Université de Bordeaux, Bordeaux; [m]Unité du Rachis, Centre Orthopédique Santy, Lyon; [n]Institut Locomoteur de l'Ouest Rachis, Centre Hospitalier Privé Saint-Grégoire, Rennes; [o]Institut Méditerranéen du Dos, Marseille, Marseille; and [p]Pôle Santé Publique, Hôpitaux Universitaires de Strasbourg, France.

Acknowledgment date: March 10, 2022. First revision date: June 3, 2022. Acceptance date: June 3, 2022.

Y.P.C. is consultant for Stryker, Clariance, SpineVision, Philips and Ceraver; he received royalties and grants unrelated to this study from Stryker and Clariance. B.I. is consultant for Zimmer Biomet, Medtronic and Implanet. B.B. is associate editor for OTSR Elsevier-Masson and consultant for Medicrea, Medtronic, Implanet, Vexim Stryker, and 3M. F.L. is consultant for Spineart and SMAIO. Guillaume Riouallon is consultant for Medtronic, Stryker and NewClip; he received royalties from Euros. V.C. is shareholder of Follow Health SA and consultant for Clariance. I.O. is consultant for Medtronic and Depuy Synthes; he received grants from DePuy Synthes unrelated to this study and royalties from Clariance, Alphatec and Spineart. L.B.is consultant for Neo and Euros; he received grants from DePuy Synthes unrelated to this study. F.S. received funding to attend meetings from Medicrea, Medtronic and Euros. J.-C.L.H. is consultant for Medtronic and BD Bard; he received royalties and grants unrelated to this study from Medtronic. V.F. is consultant for Clariance; he received royalties Medicrea and Clariance. A.F. is consultant for OSD. The remaining authors report no conflicts of interest.

Address correspondence and reprint requests to Yann P. Charles, MD, PhD, Service de Chirurgie du Rachis, Hôpitaux Universitaires de Strasbourg, 1 Avenue Molière, Strasbourg 67200, France; E-mail: yannphilippe.charles@chru-strasbourg.fr

DOI: 10.1097/BRS.0000000000004411

**Key words:** sagittal alignment, radiographic parameters, age, growth, pelvic incidence, spinopelvic morphology, Roussouly classification
**Level of Evidence:** 3
**Spine 2022;47:1303–1313**

Sagittal alignment of the trunk varies during growth and different physiologic patterns have been clinically described as neutral, sway-back, and leaning-forward positions.[1] Gender-specific differences exist during prepubertal and pubertal growth stages.[2] Similar observations were made on radiographs, where segmental thoracolumbar alignment differed by growth stage, with lower thoracic kyphosis (TK) in girls during peak height velocity.[3] Accurate TK and lumbar lordosis (LL) assessment is essential when treating patients with spinal deformity. In clinical practice, relationships between TK, LL, and spinopelvic alignment parameters may be used for surgical planning in adolescent idiopathic scoliosis.[4]

Proportionate kyphosis and lordosis distribution according to spinopelvic configuration should be considered. As sagittal pelvic width increases during growth, pelvic incidence (PI) augments from childhood to adulthood.[5] These growth-related changes of pelvic anatomy trigger the thoracolumbar shape and global trunk alignment.[6,7] In adults, relationships between PI, LL, and TK are well established.[8] It remains unclear to what extent they can be applied to children and adolescents. Roussouly *et al*[9] described four alignment types in asymptomatic adults, based on sacral slope (SS), thoracolumbar inflection point, and lumbar apex, the distribution between cranial and caudal arch of LL. This classification was completed by a fifth subtype with typical pelvic anteversion, mainly in younger subjects.[10]

The Roussouly classification has not been validated for children and adolescents, and it remains unclear how proportions of alignment types vary according to gender, PI, and age. We hypothesize that normal variations exist during growth.

The purpose of this observational study was to describe spinopelvic alignment types by age and PI, and to compare the Roussouly classification between pediatric and adult populations without spinal deformity.

## MATERIALS AND METHODS

Institutional review board approval (FC/2019-91) was obtained for this retrospective cross-sectional study on full spine radiographs that were prospectively collected in a national spine registry involving 16 centers. Sagittal radiographs (EOS Imaging, Paris, France) performed on patients with limb length inequality <2 cm, spondylolysis, screening in children with positive scoliosis family history, common low back, neck or radicular pain from September 2019 to March 2020 were used. Exclusion criteria were spinal deformity such as scoliosis (Cobb angle $>10°$), Scheuermann kyphosis, or spondylolisthesis more than grade 1, spinal or pelvic fractures, tumors, infection, and neuromuscular disorders, previous spine surgery, and severe degenerative changes leading to thoracolumbar deformity. In adults, mild intervertebral disc degeneration or facet joint osteoarthritis were considered to belong to the normal aging process and were not excluded.

Anatomical landmarks were reconstructed on sagittal radiographs from the femoral heads to the external auditory meatus by a trained operator per center using KEOPS software (SMAIO, Lyon, France). Five senior spine surgeons checked each reconstruction to minimize inter-rater errors. This method was described as reliable and superior to manual measurements.[11] Global alignment parameters included: C7 sagittal vertical axis (SVA),[12] T1-pelvic angle (TPA),[13] and spinosacral angle (SSA).[14] Spinopelvic parameters PI, PT, and SS were measured. TK included all vertebrae in kyphotic position and was measured between cervicothoracic and thoracolumbar inflexion points. LL covered all vertebrae in lordotic position and was measured between the thoracolumbar inflexion point and the S1 endplate. The cranial LL arch was measured between the thoracolumbar inflexion point and the lumbar apex, and the caudal LL arch between apex and S1 endplate. The levels of the thoracolumbar inflexion point and lumbar apex were assessed.

The Roussouly types[9,10] were morphologically classified using KEOPS software's algorithm and reviewed by five experts according to following criteria (Fig. 1):

- Type 1 has a distal lumbar apex, usually L5, with a minimal distal arch and low thoracolumbar inflexion point, resulting in a long thoracolumbar kyphosis with a back-tilt position. SS is <35° and PI is usually small.
- Type 2 has a distal lumbar apex, usually L4, with flat LL and TK curvatures and higher thoracolumbar inflexion point. SS is <35° and PI is usually small.
- Type 3 has a lumbar apex usually at L4 or L3. It appears as a balanced type between LL and TK, with an inflexion point at the thoracolumbar junction. SS is between 35 and 45° and PI is usually intermediate.
- Type 3A has a lumbar apex usually located at L3 or higher. It is characterized by an anteverted pelvic position with low or negative PT. SS is $>35°$ and PI is usually small.
- Type 4 has a lumbar apex at L3 or higher, with large LL and TK curvatures, and high thoracolumbar inflexion point. SS is $>45°$ and PI is usually large.

In the global cohort, ages ranged from 5 to 49 years. Individuals $\leq 19$ years old were stratified according to prepubertal and pubertal growth stages described by Diméglio,[15,16] using chronological age and skeletal maturity markers visible on EOS radiographs. Children and adolescents were then compared with adults:

- Group 1—prepubertal period: age from 5 to below 10 years in girls and below 12 years in boys, triradiate cartilage open, Risser 0.
- Group 2—beginning of pubertal growth: age 10 years or above in girls and 12 years or above in boys, triradiate cartilage open, Risser 0.

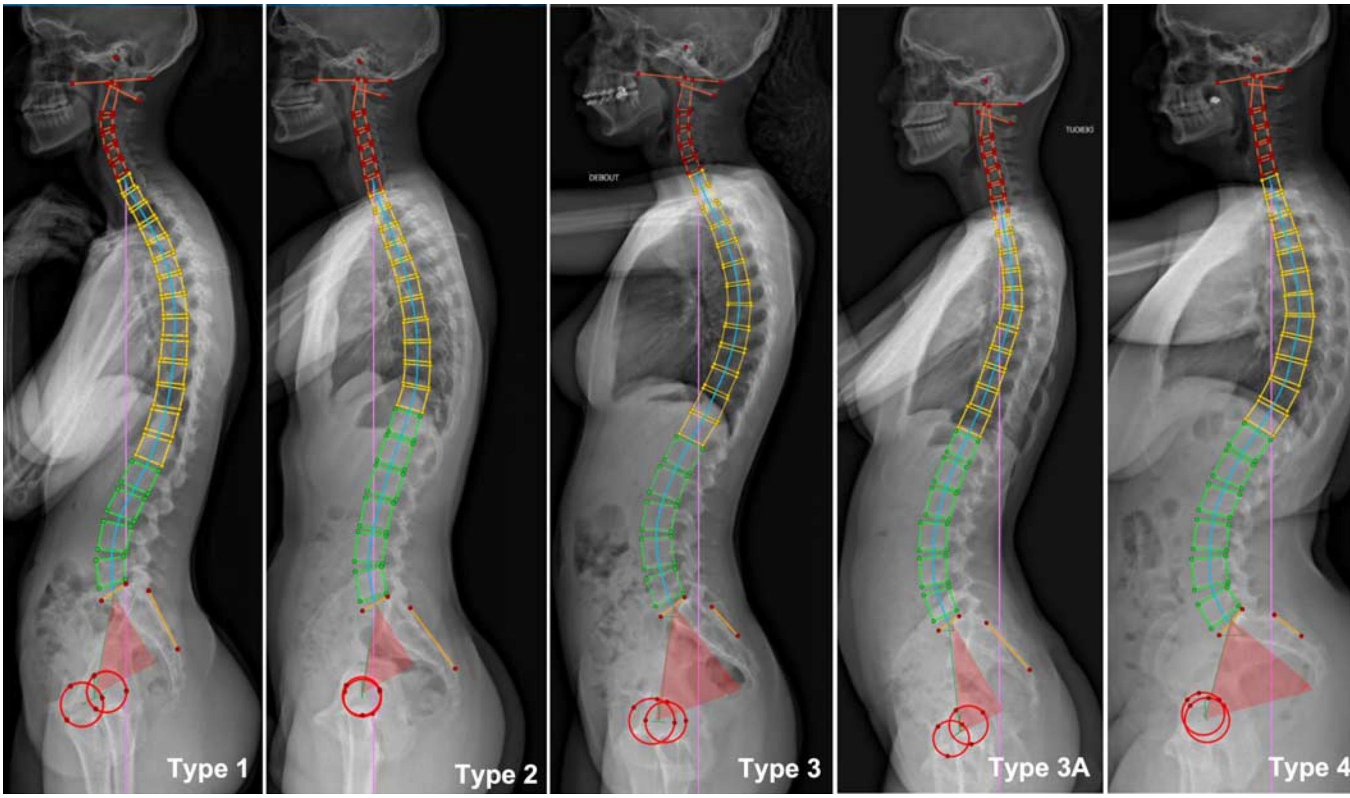


**Figure 1.** Roussouly types showing typical segmental lumbar lordosis and thoracic kyphosis distribution with pelvic incidence marked as red triangle. full color online

- Group 3—pubertal peak: triradiate cartilage closed, Risser 0 or 1.
- Group 4—decelerating growth phase: triradiate cartilage closed, Risser 2 or 3.
- Group 5—end of pubertal growth: age 19 years or below, triradiate cartilage closed, Risser 4 or 5.
- Group 6—young adults: age 20–34 years.
- Group 7—mature adults: age 35–49 years.

Statistical evaluation was performed using Markov chain Monte Carlo techniques for Bayesian inference[17] with R Software and ad hoc packages (R Foundation for Statistical Computing, Vienna, Austria). Sensitivity analyses were carried out to assess the robustness of models. To infer the value of quantity, point estimates corresponded to the median of posterior distribution and the credible interval to its 2.5 and 97.5 percentiles. The probability (Pr) that a quantity is greater or less than 0 was calculated. The test of this difference with respect to 0 was considered as significant if this probability was $>0.975$ or $<0.025$. Radiographic parameters were compared by age group, while Group 6 (young adults) was considered as reference. The distributions of PI and Roussouly types were described by age and gender. The distributions of thoracolumbar inflexion points and lumbar apexes were described by age. The relationship between PI and age by Roussouly type was modeled using a linear regression.

## RESULTS

A total of 1706 individuals were analyzed. There were 985 females and 721 males. The distribution by age was: Group 1—n = 146, Group 2—n = 203, Group 3—n = 166, Group 4—n = 143, Group 5—n = 400, Group 6—n = 224, and Group 7—n = 424.

### Global and Spinopelvic Parameters

Table 1 demonstrates the distribution of global alignment parameters across age groups. The SVA C7 decreased during puberty and reached a minimum mean value of –0.3 mm in young adults (Group 6). The 95% credible intervals showed large ranges including negative values (C7 plumbline posterior to S1). Values were higher in all age groups compared with Group 6, with a strong significant difference in children during the prepubertal period (Group 1; $Pr > 0.9999$) and in adults aged 35–49 years (group 7; $Pr > 0.9999$). The TPA increased during growth. Group 7 had a significantly larger TPA compared with Group 6 ($Pr > 0.9999$). The SSA remained relatively constant and there were no significant differences between the growth period and adulthood.

Table 2 displays thoracolumbar kyphosis and lordosis values. TK increased during the growth period and remained similar between adult groups 6 and 7. TK was significantly smaller in Groups 1–5 compared with Group 6 ($Pr < 0.025$). LL increased significantly during growth (Groups 1–5) and values were significantly lower compared

**TABLE 1. Distribution of Global Alignment Parameters for Age Groups 1–7: Mean ± SD, Median of Posterior Distributions and Symmetric 95% Credible Intervals, Posterior Probability of Significant Difference Pr(d > 0) With Respect to Group 6 (Young Adults)**

| Parameter | Age | Mean ± SD | Median | 95% CI | Pr(d > 0) |
|---|---|---|---|---|---|
| Sagittal vertical axis C7 (mm) | Group 1 | 19.1 ± 33.1 | 18.0 | [13.2; 22.9] | > 0.9999 |
| | Group 2 | 10.2 ± 29.0 | 9.7 | [5.6; 13.8] | 0.9998 |
| | Group 3 | 6.7 ± 31.4 | 6.4 | [1.9; 11.0] | 0.9828 |
| | Group 4 | 7.9 ± 26.8 | 7.5 | [2.6; 12.4] | 0.9923 |
| | Group 5 | 3.9 ± 25.7 | 3.8 | [0.8; 6.8] | 0.9451 |
| | Group 6 | −0.3 ± 33.8 | −0.3 | [−4.1; 3.6] | Reference |
| | Group 7 | 12.3 ± 33.3 | 12.1 | [9.2; 15.0] | > 0.9999 |
| T1-pelvic angle (degrees) | Group 1 | 5.9 ± 4.9 | 5.9 | [4.9; 6.9] | $< 8.4\times10^{-5}$ |
| | Group 2 | 6.2 ± 5.0 | 6.2 | [5.3; 7.0] | $< 8.4\times10^{-5}$ |
| | Group 3 | 7.6 ± 5.5 | 7.5 | [6.6; 8.4] | 0.0506 |
| | Group 4 | 7.2 ± 5.1 | 7.2 | [6.2; 8.2] | 0.0166 |
| | Group 5 | 7.4 ± 5.5 | 7.4 | [6.8; 8.0] | 0.0122 |
| | Group 6 | 8.5 ± 5.9 | 8.8 | [7.7; 9.3] | Reference |
| | Group 7 | 11.6 ± 7.7 | 11.6 | [11.0; 12.1] | > 0.9999 |
| Spinosacral angle (degrees) | Group 1 | 125.5 ± 9.1 | 124.8 | [123.2; 126.3] | $< 8.4\times10^{-5}$ |
| | Group 2 | 129.2 ± 8.5 | 128.6 | [127.3; 129.9] | 0.2255 |
| | Group 3 | 128.5 ± 9.5 | 127.8 | [126.3; 129.2] | 0.0562 |
| | Group 4 | 128.4 ± 9.6 | 127.6 | [126.1; 129.2] | 0.0502 |
| | Group 5 | 128.4 ± 9.3 | 128.1 | [127.2; 129.0] | 0.0613 |
| | Group 6 | 129.8 ± 9.5 | 129.3 | [128.1; 130.5] | Reference |
| | Group 7 | 127.9 ± 9.8 | 127.6 | [126.7; 128.5] | 0.0147 |

with young adults in Group 6 (Pr < 0.025). The main LL increase occurred in the cranial arch with significant differences between Groups 1 and 4 and Group 6 (Pr < 0.025). Caudal arch lordosis remained relatively constant.

Table 3 demonstrates pelvic parameters. PI increased during growth with significant differences between Groups 1 and 5 and Group 6 (Pr < 0.025). Similar observations were made for PT, which further increased during adulthood and was significantly larger in Group 7 compared with Group 6 (Pr > 0.9999). SS remained relatively constant throughout the growth period and in adults.

## Distribution of PI

PI was divided in three categories to classify spinopelvic configurations. Thresholds for PI groups were determined according to first (44.2°) and third (60.5°) quartiles for young adults (Group 6): low PI <45°, medium PI 45°–60°, high PI >60°. The distribution of PI according to age is demonstrated in Table 4. In children and adolescents low PI accounted for the largest proportion. Its frequency was significantly higher (Pr > 0.99) compared with Group 6. High PI represented the lowest proportion in Groups 1–5. In adults, intermediate PI represented the largest proportion, and high PI was significantly more frequent in Group 7 compared with Group 6 (Pr = 9771). When comparing PI between genders in respective age groups, there was no significant difference in children and adolescents. Only in Group 7, the proportion of low PI was significantly smaller (Pr = 0.9950), and the proportion of high PI was significantly larger (Pr = 0.9840) in females.

## Lumbar Apex and Thoracolumbar Inflexion Point

Table 5 gives an overview of lumbar apexe and thoracolumbar inflexion point distribution. Proportions

**TABLE 2. Distribution of Spinal Alignment Parameters for Age and Growth Groups 1–7: Mean ± SD, Median of Posterior Distributions and Symmetric 95% Credible Intervals, Posterior Probability of Significant Difference Pr(d > 0) With Respect to Group 6 (Young Adults)**

| Parameter | Age | Mean ± SD | Median | 95% CI | Pr(d > 0) |
|---|---|---|---|---|---|
| Thoracic kyphosis (degrees) | Group 1 | 40.8 ± 10.7 | 40.5 | [38.6; 42.3] | 0.0028 |
| | Group 2 | 39.3 ± 10.9 | 39.1 | [37.5; 40.6] | 0.0001 |
| | Group 3 | 39.9 ± 12.3 | 39.6 | [37.8; 41.3] | 0.0001 |
| | Group 4 | 41.9 ± 11.3 | 41.5 | [39.7; 43.4] | 0.0237 |
| | Group 5 | 41.8 ± 11.0 | 41.6 | [40.5; 42.7] | 0.0068 |
| | Group 6 | 44.2 ± 12.3 | 44.0 | [42.5; 45.5] | Reference |
| | Group 7 | 45.0 ± 11.4 | 44.8 | [43.7; 45.9] | 0.8193 |
| Lumbar lordosis (degrees) | Group 1 | 50.5 ± 11.2 | 50.0 | [48.0; 51.9] | $<8.4\times10^{-5}$ |
| | Group 2 | 54.3 ± 11.0 | 53.9 | [52.2; 55.5] | 0.0002 |
| | Group 3 | 53.7 ± 12.3 | 53.2 | [51.4; 55.0] | $<8.4\times10^{-5}$ |
| | Group 4 | 55.8 ± 11.5 | 55.3 | [53.3; 57.2] | 0.0186 |
| | Group 5 | 55.6 ± 11.7 | 55.4 | [54.3; 56.6] | 0.0059 |
| | Group 6 | 58.3 ± 12.0 | 57.9 | [56.3; 59.5] | Reference |
| | Group 7 | 55.9 ± 12.8 | 55.7 | [54.6; 56.9] | 0.0126 |
| Cranial arch lordosis (degrees) | Group 1 | 15.1 ± 6.1 | 15.1 | [14.1; 16.1] | $<8.4\times10^{-5}$ |
| | Group 2 | 16.8 ± 6.3 | 16.8 | [15.9; 17.7] | $<8.4\times10^{-5}$ |
| | Group 3 | 17.3 ± 6.3 | 17.2 | [16.3; 18.2] | $<8.4\times10^{-5}$ |
| | Group 4 | 18.9 ± 6.3 | 18.8 | [17.8; 19.9] | 0.0207 |
| | Group 5 | 19.4 ± 5.9 | 19.4 | [18.8; 20.0] | 0.0658 |
| | Group 6 | 20.2 ± 6.3 | 20.2 | [19.4; 21.0] | Reference |
| | Group 7 | 19.2 ± 6.4 | 19.2 | [18.6; 19.8] | 0.0198 |
| Caudal arch lordosis (degrees) | Group 1 | 36.2 ± 7.5 | 36.0 | [34.6; 37.4] | 0.0138 |
| | Group 2 | 38.8 ± 7.8 | 38.7 | [37.5; 39.9] | 0.7470 |
| | Group 3 | 37.8 ± 9.0 | 37.6 | [36.3; 39.0] | 0.2890 |
| | Group 4 | 37.8 ± 9.2 | 37.6 | [36.1; 39.0] | 0.2858 |
| | Group 5 | 37.2 ± 9.2 | 37.2 | [36.4; 38.1] | 0.1225 |
| | Group 6 | 38.2 ± 9.0 | 38.1 | [36.9; 39.3] | Reference |
| | Group 7 | 37.7 ± 9.2 | 37.6 | [36.7; 38.4] | 0.2440 |

remained similar across age Groups 1–7. The lumbar apex was located at L3 or L4 in more than 80% in each group. The thoracolumbar inflexion point was located at T11, T12, or L1 in more than 70% in each group.

## Distribution of Roussouly Types

Table 6 demonstrates the distribution of Roussouly types. Type 1 was less frequent than other types. Type 2 was most frequent. For both types, there were no significant differences in proportions throughout age Groups 1–5 compared with Group 6. The proportions of Types 3 and 4 were significantly lower during the prepubertal period (Group 1; Pr < 0.025). Differences between Groups 2and 5 and Group 6 were nonsignificant. Type 3A was mainly represented in the pediatric and adolescent population and proportions decreased in adults. There was a strong

**TABLE 3. Distribution of Pelvic Parameters for Age and Growth Groups 1–7: Mean ± SD, Median of Posterior Distributions and Symmetric 95% Credible Intervals, Posterior Probability of Significant Difference Pr(d > 0) With Respect to Group 6 (Young Adults)**

| Parameter | Age—Growth | Mean ± SD | Median | 95% CI | Pr(d > 0) |
|---|---|---|---|---|---|
| Pelvic incidence (degrees) | Group 1 | 40.4 ± 9.1 | 40.0 | [38.1; 41.9] | $< 8.4 \times 10^{-5}$ |
| | Group 2 | 43.7 ± 10.5 | 43.4 | [41.8; 45.0] | $< 8.4 \times 10^{-5}$ |
| | Group 3 | 44.7 ± 11.9 | 44.4 | [42.6; 46.1] | $< 8.4 \times 10^{-5}$ |
| | Group 4 | 44.7 ± 10.5 | 44.3 | [42.4; 46.2] | $< 8.4 \times 10^{-5}$ |
| | Group 5 | 45.8 ± 11.9 | 45.7 | [44.5; 46.8] | $< 8.4 \times 10^{-5}$ |
| | Group 6 | 50.1 ± 11.3 | 49.8 | [48.3; 51.3] | Reference |
| | Group 7 | 52.7 ± 12.5 | 52.6 | [51.5; 53.7] | 0.9985 |
| Pelvic tilt (degrees) | Group 1 | 4.2 ± 7.2 | 4.1 | [2.8; 5.4] | $< 8.4 \times 10^{-5}$ |
| | Group 2 | 4.8 ± 8.1 | 4.8 | [3.7; 5.9] | $< 8.4 \times 10^{-5}$ |
| | Group 3 | 7.0 ± 9.0 | 6.9 | [5.7; 8.1] | $< 8.4 \times 10^{-5}$ |
| | Group 4 | 7.0 ± 8.0 | 6.9 | [5.6; 8.3] | $< 8.4 \times 10^{-5}$ |
| | Group 5 | 8.5 ± 8.0 | 8.5 | [7.7; 9.3] | $< 8.4 \times 10^{-5}$ |
| | Group 6 | 11.9 ± 7.0 | 11.8 | [10.8; 12.9] | Reference |
| | Group 7 | 15.1 ± 8.2 | 15.1 | [14.3; 15.8] | > 0.9999 |
| Sacral slope (degrees) | Group 1 | 36.2 ± 7.5 | 36.0 | [34.6; 37.4] | 0.0118 |
| | Group 2 | 38.8 ± 7.8 | 38.7 | [37.5; 39.9] | 0.7490 |
| | Group 3 | 37.8 ± 9.0 | 37.6 | [36.2; 38.9] | 0.2840 |
| | Group 4 | 37.8 ± 9.2 | 37.6 | [36.1; 39.0] | 0.2886 |
| | Group 5 | 37.3 ± 9.2 | 37.2 | [36.4; 38.1] | 0.1256 |
| | Group 6 | 38.2 ± 9.0 | 38.1 | [36.9; 39.3] | Reference |
| | Group 7 | 37.7 ± 9.2 | 37.6 | [36.7; 38.4] | 0.2480 |

significant difference for Groups 1 and 2 compared with Group 6 (Pr > 0.9999) and proportions remained significantly higher in Groups 3–5 (Pr > 0.99). The distribution of Roussouly types was similar between female and male.

### Relationship Between PI and Roussouly Types

The distribution of mean PI values, standard deviations and 95% credible intervals by Roussouly type was: Type 1 38.0 ± 8.6° (22.9–52.9°), Type 2 39.3 ± 8.4° (23.3–56.7°), Type 52.3 ± 5.7° (42.8–64.7°), Type 3A 39.4 ± 5.2° (29.4–48.1°), Type 4 61.3 ± 11.3° (49.0–81.2°).

Figure 2 shows the distribution of Roussouly Types according to SS categories <35°, 35–45° or > 45°, as described in this classification. When implementing PI and spinopelvic shape, grey zones appeared: Zone 1, where SS > 45° would match with Type 4 and low PI with Type 3A, and Zone 2, where SS 35–45° would match with Type 3 and high PI with Type 4.

Figure 3 demonstrates the relationship between PI and age by Roussouly type using a linear regression. PI increased with age, as each curve slope was > 0, regardless of Roussouly type. There were no significant differences between slopes for Types 1, 2, 3, and 3A, which were 0.9899, 1.4492, 0.8608, and 0.4948 respectively. The slope of Type 4 was 2.6824 and significantly superior to all other slopes (Pr > 0.9999).

## DISCUSSION

Sagittal alignment and the effect of aging has been described in adults.[8–14,18,19] When analyzing children and adolescents, differences exist compared with adults.[7] Specific knowledge about normal sagittal alignment during growth is mandatory when treating scoliosis or hyperkyphosis patients conservatively with a brace, or when planning surgical correction of their spinal deformity. When considering global alignment, SVA C7 represents a commonly used

**TABLE 4. Distribution of Pelvic Incidence (PI) Per Age and Growth Group 1–7 for the Global Population and by Gender, and Posterior Probability of Significant Difference Pr(d > 0) With Respect to Group 6 (Young Adults)**

| | | Low PI <45° | | Medium PI 45–60° | | High PI >60° | |
|---|---|---|---|---|---|---|---|
| Population | Age | n = 797, n (%) | Pr(d > 0) | n = 652, n (%) | Pr(d > 0) | n = 257, n (%) | Pr(d > 0) |
| Global n = 1706 | Group 1 | 108 (74.0) | > 0.9999 | 32 (21.9) | $< 8.4\times10^{-5}$ | 6 (4.1) | $< 8.4\times10^{-5}$ |
| | Group 2 | 112 (55.2) | 0.9999 | 75 (36.9) | 0.0756 | 16 (7.9) | 0.0002 |
| | Group 3 | 87 (52.4) | 0.9983 | 63 (38.0) | 0.1328 | 16 (9.6) | 0.0050 |
| | Group 4 | 83 (58.0) | > 0.9999 | 47 (32.9) | 0.0163 | 13 (9.1) | 0.0038 |
| | Group 5 | 204 (51.0) | 0.9998 | 144 (36.0) | 0.0280 | 52 (13.0) | 0.0201 |
| | Group 6 | 83 (37.1) | Reference | 98 (43.8) | Reference | 43 (19.2) | Reference |
| | Group 7 | 120 (28.3) | 0.0108 | 193 (45.5) | 0.6700 | 111 (26.2) | 0.9771 |
| | | n = 443 | Pr(d > 0) | n = 382 | Pr(d > 0) | n = 160 | Pr(d > 0) |
| Females n = 985 | Group 1 | 46 (73.0) | > 0.9999 | 14 (22.2) | 0.0037 | 3 (4.8) | 0.0016 |
| | Group 2 | 67 (56.3) | 0.9918 | 43 (36.1) | 0.2067 | 9 (7.6) | 0.0041 |
| | Group 3 | 54 (47.4) | 0.8578 | 48 (42.1) | 0.5632 | 12 (10.5) | 0.0342 |
| | Group 4 | 40 (54.1) | 0.9702 | 26 (35.1) | 0.1948 | 8 (10.8) | 0.0654 |
| | Group 5 | 137 (50.2) | 0.9676 | 98 (35.9) | 0.1638 | 38 (13.9) | 0.1124 |
| | Group 6 | 48 (40.3) | Reference | 49 (41.2) | Reference | 22 (18.5) | Reference |
| | Group 7 | 51 (22.9) | 0.0005 | 104 (46.6) | 0.1492 | 68 (30.5) | 0.9906 |
| | | n = 354 | Pr(d > 0) | n = 270 | Pr(d > 0) | n = 97 | Pr(d > 0) |
| Males n = 721 | Group 1 | 62 (74.7) | > 0.9999 | 18 (21.7) | 0.0002 | 3 (3.6) | 0.0001 |
| | Group 2 | 45 (53.6) | 0.9987 | 32 (38.1) | 0.1158 | 7 (8.3) | 0.0092 |
| | Group 3 | 33 (63.5) | > 0.9999 | 15 (28.8) | 0.0138 | 4 (7.7) | 0.0138 |
| | Group 4 | 43 (62.3) | 0.9999 | 21 (30.4) | 0.0162 | 5 (7.2) | 0.0078 |
| | Group 5 | 67 (52.8) | 0.9986 | 46 (36.2) | 0.0462 | 14 (11.0) | 0.0395 |
| | Group 6 | 35 (33.3) | Reference | 49 (46.7) | Reference | 21 (20.0) | Reference |
| | Group 7 | 69 (34.3) | 0.5718 | 89 (44.3) | 0.3394 | 43 (21.4) | 0.3639 |

translation parameter, and values below 50 mm are considered as normal in adults.[12] Vedantam *et al*[7] reported smaller and even negative SVA values in adolescents. Mac-Thiong *et al*[6] described a progressive C7 plumbline displacement behind the hip axis between the age of 3 years until skeletal maturity. A decrease during the growth period was also observed in our cohort. This might be linked to erector spinae muscle strength which increases at the end of pubertal growth and in young adults. Furthermore, changes in spinopelvic parameters, TK and LL distribution might play a role. TPA represents another global alignment parameter which is strongly related to PI and PT.[13] TPA increased between the prebubertal period, the beginning pubertal growth spurt and adult groups. This might be explained by PI and PT increase during growth, which is concordant with previous studies.[3,5,21,22] On the other hand, SSA variations were small during the growth period, which confirms previous findings of Mac-Thiong *et al*[6] and Wang *et al*.[23] This parameter is mainly linked to SS,[14] which remained relatively constant in our study.

A strong relationship between PI, PT and SS has been demonstrated in adults, which is linked to the amount of LL.[8,19] Mac-Thiong *et al*[24] found that these parameters were also correlated in children and adolescents, although differences existed when comparing to adults. Mac-Thiong *et al*,[5] Abelin-Genevois *et al*,[21] and Hou *et al*[22] demonstrated that

**TABLE 5. Distribution of Lumbar Apex and Thoracolumbar Inflexion Point Per Age and Growth Group 1–7 for the Global Population**

| | | L1, n (%) | L2, n (%) | L3, n (%) | L4, n (%) | L5, n (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Total** | **n = 18** | **n = 147** | **n = 812** | **n = 661** | **n = 68** | | | |
| Lumbar apex | Group 1 | 2 (1.4) | 13 (8.9) | 61 (41.8) | 65 (44.5) | 5 (3.4) | | | |
| | Group 2 | 4 (2.0) | 14 (6.9) | 103 (50.7) | 74 (36.5) | 8 (3.9) | | | |
| | Group 3 | 2 (1.2) | 12 (7.2) | 74 (44.6) | 73 (44.0) | 5 (3.0) | | | |
| | Group 4 | 0 (0.0) | 8 (5.6) | 77 (53.8) | 49 (34.3) | 9 (6.3) | | | |
| | Group 5 | 4 (1.0) | 43 (10.7) | 207 (51.8) | 132 (33.0) | 14 (3.5) | | | |
| | Group 6 | 2 (1.0) | 15 (6.7) | 100 (44.6) | 100 (44.6) | 7 (3.1) | | | |
| | Group 7 | 3 (1.0) | 42 (9.9) | 190 (44.8) | 168 (39.6) | 20 (4.7) | | | |
| | | **T8, n (%)** | **T9, n (%)** | **T10, n (%)** | **T11, n (%)** | **T12, n (%)** | **L1, n (%)** | **L2, n (%)** | **L3, n (%)** |
| | **Total** | **n = 33** | **n = 64** | **n = 121** | **n = 416** | **n = 492** | **n = 425** | **n = 134** | **n = 21** |
| Thoracolumbar inflexion point | Group 1 | 2 (1.3) | 10 (6.9) | 10 (6.9) | 39 (26.7) | 38 (26.0) | 33 (22.6) | 10 (6.9) | 4 (2.7) |
| | Group 2 | 5 (2.4) | 7 (3.5) | 19 (9.4) | 49 (24.1) | 51 (25.1) | 46 (22.7) | 23 (11.3) | 3 (1.5) |
| | Group 3 | 5 (3.0) | 3 (1.8) | 22 (13.3) | 39 (23.5) | 32 (19.3) | 46 (27.7) | 18 (10.8) | 1 (0.6) |
| | Group 4 | 3 (2.1) | 4 (2.8) | 12 (8.4) | 33 (23.1) | 37 (25.9) | 41 (28.7) | 10 (7.0) | 3 (2.1) |
| | Group 5 | 4 (1.0) | 15 (3.7) | 32 (8.0) | 102 (25.5) | 122 (30.5) | 92 (23.0) | 30 (7.5) | 3 (0.8) |
| | Group 6 | 4 (1.8) | 8 (3.6) | 6 (2.7) | 59 (26.3) | 70 (31.2) | 61 (27.2) | 16 (7.1) | 0 (0.0) |
| | Group 7 | 10 (2.4) | 17 (4.0) | 20 (4.7) | 95 (22.4) | 142 (33.5) | 106 (25.0) | 27 (6.4) | 7 (1.6) |

PI increased during growth before stabilizing at skeletal maturity. From childhood to adulthood, the pelvic position parameter PT increased most likely to avoid anterior displacement of body center gravity, whereas SS was achieved with standing posture without age-related changes.[5,22] Our results are concordant with these findings. Since PI and LL are correlated in pediatric populations,[21,24] a global TK and LL increase might be observed during growth. TK and LL values in our cohort were like previous values for Caucasian children and adolescents.[3–5,21,24,25] Values were smaller for corresponding Chinese populations.[22,23] Sullivan *et al*[20] used these relationships to establish a predictive model for LL based on PI. Clément *et al*[4] described a calculation method of TK using PI, PT, and LL when planning surgical scoliosis correction. Nevertheless, these formulae might be misleading when calculating global LL and TK without considering segmental kyphosis and lordosis distribution, including variable levels of thoracolumbar inflexion point, thoracic and lumbar apex.

Schlösser *et al*[3] and Wang *et al*[23] described lower TK and posteriorly inclined T7-T12 segment in girls during the pubertal growth spurt. Pesenti *et al*[18] demonstrated that proximal LL was strongly related to PI in adults. Our results showed that LL mainly increased in the cranial arch during growth, including a large proportion of children and adolescents with low PI, which was different from adults. Vendatam *et al*[7] described a large lumbar apex variation from L2 to L5 in adolescents. They found a correlation between negative SVA, more proximal thoracic apex, greater distance from T12 and lumbar apex to C7 plumbline, with the hips as center of rotation. This pattern was later described as Roussouly Type 3A with typical pelvic anteversion, long LL and small PI.[10] Our results demonstrated that this pattern was mainly present in the pediatric population, whereas Type 3A was rare after 35 years. Uneven vertebral body growth might play a role.[3] However, logistic regression showed that PI increased differently across age groups when classifying by Roussouly type. There was a trend from small to intermediate PI and from Type 3A to 3 from childhood to adulthood. Proportions of high PI and Type 4 were larger in adults, indicating that spinopelvic alignment might change between the growth period and skeletal maturity.

This cross-sectional study has limitations as the evolution of alignment parameters cannot be assessed longitudinally over the entire growth period and during adulthood. Small differences of arm position were observed between patients, which might have influenced TK. Serial clinical height

**TABLE 6. Distribution of Roussouly Types per Age and Growth Group 1–7 for the Global Population and by Gender, and Posterior Probability of Significant Difference Pr(d > 0) With Respect to Group 6 (Young Adults)**

| Population | Age | Type 1 | | Type 2 | | Type 3 | | Type 3A | | Type 4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n = 95, n (%) | Pr(d > 0) | n = 545, n (%) | Pr(d > 0) | n = 457, n (%) | Pr(d > 0) | n = 261, n (%) | Pr(d > 0) | n = 348, n (%) | Pr(d > 0) |
| Global n = 1706 | Group 1 | 7 (4.8) | 0.6384 | 53 (36.3) | 0.8949 | 23 (15.8) | $< 8.4 \times 10^{-5}$ | 48 (32.9) | > 0.9999 | 15 (10.3) | 0.0003 |
| | Group 2 | 11 (5.4) | 0.7599 | 51 (25.1) | 0.1397 | 48 (23.6) | 0.0114 | 49 (24.1) | > 0.9999 | 44 (21.7) | 0.3159 |
| | Group 3 | 6 (3.6) | 0.4038 | 50 (30.3) | 0.5212 | 39 (23.6) | 0.0158 | 33 (20.0) | 0.9997 | 37 (22.4) | 0.3766 |
| | Group 4 | 10 (7.0) | 0.8976 | 44 (30.8) | 0.5645 | 30 (21.0) | 0.0021 | 28 (19.6) | 0.9910 | 31 (21.7) | 0.3206 |
| | Group 5 | 24 (6.0) | 0.8742 | 140 (35.0) | 0.9005 | 103 (25.8) | 0.0162 | 67 (16.8) | 0.9910 | 66 (16.5) | 0.0127 |
| | Group 6 | 9 (4.0) | Reference | 67 (29.9) | Reference | 76 (33.9) | Reference | 19 (8.5) | Reference | 53 (23.7) | Reference |
| | Group 7 | 28 (6.6) | 0.9242 | 140 (33.0) | 0.7854 | 138 (32.3) | 0.3373 | 17 (4.0) | 0.0097 | 102 (24.1) | 0.5415 |
| | | n = 48 | Pr(d > 0) | n = 295 | Pr(d > 0) | n = 263 | Pr(d > 0) | n = 159 | Pr(d > 0) | n = 220 | Pr(d > 0) |
| Females n = 985 | Group 1 | 2 (3.2) | 0.4417 | 22 (34.9) | 0.8062 | 9 (14.3) | 0.0018 | 24 (38.1) | > 0.9999 | 6 (9.5) | 0.0045 |
| | Group 2 | 5 (4.2) | 0.6461 | 27 (22.7) | 0.1453 | 25 (21.0) | 0.0233 | 32 (26.9) | 0.9994 | 30 (25.2) | 0.5515 |
| | Group 3 | 4 (3.5) | 0.5494 | 38 (33.6) | 0.7881 | 29 (25.7) | 0.1355 | 16 (14.2) | 0.7512 | 26 (23.0) | 0.3739 |
| | Group 4 | 7 (9.5) | 0.9650 | 19 (25.7) | 0.3465 | 12 (16.2) | 0.0029 | 16 (21.6) | 0.9745 | 20 (27.0) | 0.6449 |
| | Group 5 | 14 (5.1) | 0.7929 | 88 (32.2) | 0.7747 | 72 (26.4) | 0.1062 | 51 (18.7) | 0.9761 | 48 (17.6) | 0.0818 |
| | Group 6 | 4 (3.4) | Reference | 34 (28.6) | Reference | 39 (32.8) | Reference | 13 (10.9) | Reference | 29 (24.4) | Reference |
| | Group 7 | 12 (5.4) | 0.8108 | 67 (30.0) | 0.6248 | 77 (34.1) | 0.5888 | 7 (3.1) | 0.0020 | 61 (27.4) | 0.7278 |
| | | n = 47 | Pr(d > 0) | n = 250 | Pr(d > 0) | n = 194 | Pr(d > 0) | n = 102 | Pr(d > 0) | n = 128 | Pr(d > 0) |
| Males n = 721 | Group 1 | 5 (6.0) | 0.6627 | 31 (37.3) | 0.8139 | 14 (16.9) | 0.0020 | 24 (28.9) | > 0.9999 | 9 (10.8) | 0.0164 |
| | Group 2 | 6 (7.1) | 0.7664 | 24 (28.6) | 0.3329 | 23 (27.4) | 0.1066 | 17 (20.2) | 0.9950 | 14 (16.7) | 0.1389 |
| | Group 3 | 2 (3.8) | 0.3619 | 12 (23.1) | 0.1197 | 10 (19.2) | 0.0187 | 17 (32.7) | > 0.9999 | 11 (21.2) | 0.3780 |
| | Group 4 | 3 (4.3) | 0.4304 | 25 (36.2) | 0.7068 | 18 (26.1) | 0.1140 | 12 (17.4) | 0.9936 | 11 (15.9) | 0.1340 |
| | Group 5 | 10 (7.9) | 0.8467 | 52 (40.9) | 0.9336 | 31 (24.4) | 0.0365 | 16 (12.6) | 0.9726 | 18 (14.2) | 0.0413 |
| | Group 6 | 5 (4.8) | Reference | 33 (31.4) | Reference | 37 (35.2) | Reference | 6 (5.7) | Reference | 24 (22.9) | Reference |
| | Group 7 | 16 (8.0) | 0.8734 | 73 (36.3) | 0.8119 | 61 (30.3) | 0.1924 | 10 (5.0) | 0.4192 | 41 (20.4) | 0.3131 |

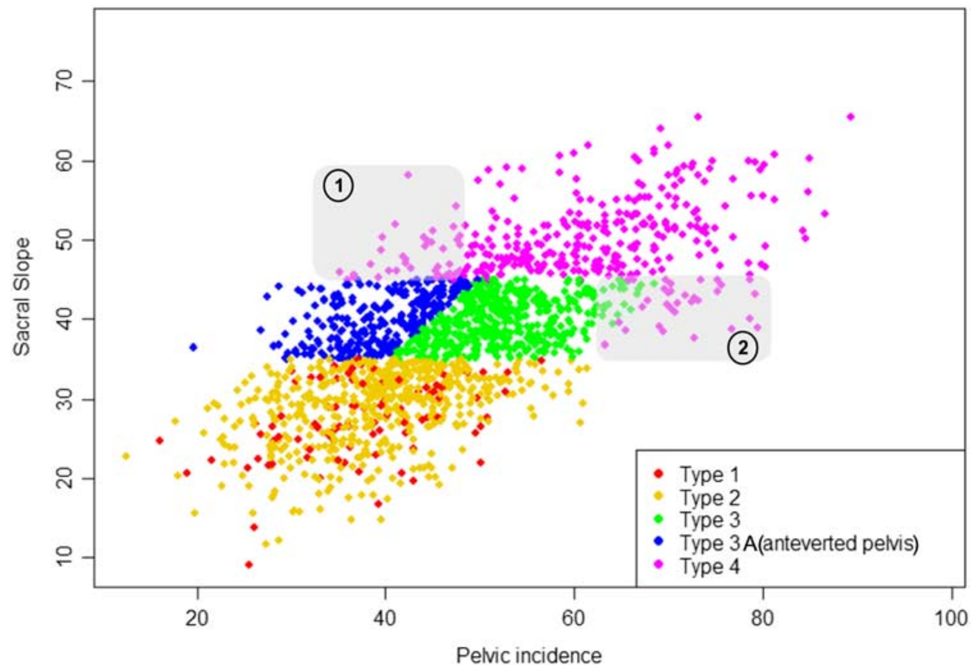


**Figure 2.** Distribution of Roussouly types according to sacral slope (SS) and pelvic incidence (PI). Grey zone 1 indicates that SS >45° would match with Type 4 and low PI with Type 3A. Grey zone 2 indicates that SS 35–45° would match with Type 3 and high PI with Type 4. full color online

measurements and digital skeletal age might be useful for more detailed determination of the growth period, which was not analyzed retrospectively. Quality of life scores were not assessed, although the clinical situation might influence radiographic alignment, especially in children with spondylolysis and in adults with mild degenerative changes.

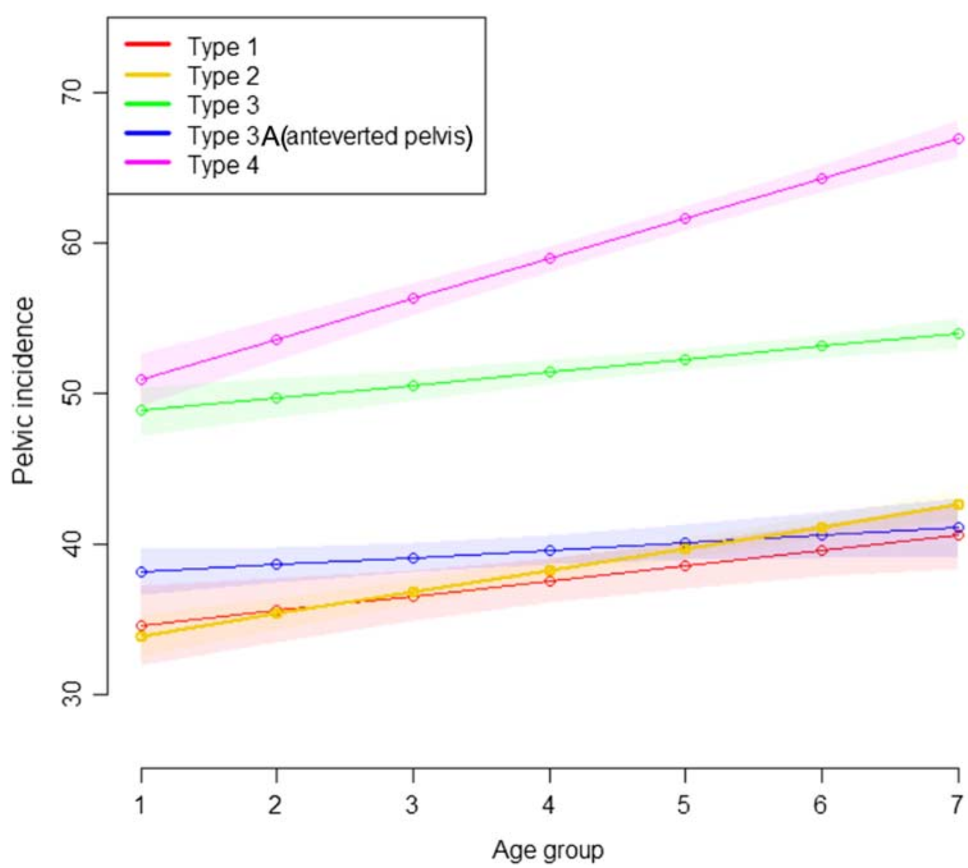


**Figure 3.** Linear regression showing the relationship between pelvic incidence and age (Groups 1–7) by Roussouly type. full color online

## CONCLUSION

Global and spinopelvic alignment changed in individuals during growth, with different kyphosis and lordosis distribution compared with adults. The growth-related PI increase influenced the distribution of Roussouly types from childhood to adulthood, with typical predominance of Type 3A in children and adolescents. Type 4 was associated with the largest PI increase across age groups. Normative data might serve as a reference when treating scoliosis patients.

## ➢ Key Points

- ❑ SVA C7 decreased, TPA, TK, LL, PI, and PT increased during the growth period.
- ❑ Small PI represented the largest proportion in children and adolescents, whereas intermediate PI was most frequent in adults.
- ❑ Spinopelvic alignment patterns changed during growth. Roussouly Type 3A, characterized by long LL, pelvic anteversion and small PI, represented a typical pattern in children and adolescents.
- ❑ Growth-related PI increase varied between Roussouly types, with the largest increase across age groups in Type 4.

### Acknowledgments

The author thanks Philippe Roussouly for technical support using the KEOPS online data base.

### References

1. Dolphens M, Cagnie B, Vleeming A, et al. Gender differences in sagittal standing alignment before pubertal peak growth: the importance of subclassification and implications for spinopelvic loading. *J Anat*. 2013;223:629–40.
2. Dolphens M, Vleeming A, Castelein R, et al. Coronal plane trunk asymmetry is associated with whole-body sagittal alignment in healthy young adolescents before pubertal peak growth. *Eur Spine J*. 2018;27:448–57.
3. Schlösser TP, Vincken KL, Rogers K, et al. Natural sagittal spino-pelvic alignment in boys and girls before, at and after the adolescent growth spurt. *Eur Spine J*. 2015;24:1158–67.
4. Clément JL, Solla F, Amorese V, et al. Lumbopelvic parameters can be used to predict thoracic kyphosis in adolescents. *Eur Spine J*. 2020;29:2281–6.
5. Mac-Thiong JM, Berthonnaud E, Dimar JR II, et al. Sagittal alignment of the spine and pelvis during growth. *Spine (Phila Pa 1976)*. 2004;29:1642–7.
6. Mac-Thiong JM, Labelle H, Roussouly P. Pediatric sagittal alignment. *Eur Spine J*. 2011;20(suppl 5):586–90.
7. Vedantam R, Lenke LG, Keeney JA, Bridwell KH. Comparison of standing sagittal spinal alignment in asymptomatic adolescents and adults. *Spine (Phila Pa 1976)*. 1998;23:211–5.
8. Vialle R, Levassor N, Rillardon L, et al. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. *J Bone Joint Surg Am*. 2005;87:260–7.
9. Roussouly P, Gollogly S, Berthonnaud E, et al. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine (Phila Pa 1976)*. 2005;30:29–34.
10. Laouissat F, Sebaaly A, Gehrchen M, Roussouly P. Classification of normal sagittal spine alignment: refounding the Roussouly classification. *Eur Spine J*. 2018;27:2002–11.
11. Maillot C, Ferrero E, Fort D, et al. Reproducibility and repeatability of a new computerized software for sagittal spinopelvic and scoliosis curvature radiologic measurements: Keops(®). *Eur Spine J*. 2015;24:1574–81.
12. Jackson RP, McManus AC. Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. A prospective controlled clinical study. *Spine (Phila Pa 1976)*. 1994;19: 1611–8.
13. Ryan DJ, Protopsaltis TS, Ames CP, et al. T1 pelvic angle (TPA) effectively evaluates sagittal deformity and assesses radiographical surgical outcomes longitudinally. *Spine (Phila Pa 1976)*. 2014;39: 1203–0.
14. Roussouly P, Nnadi C. Sagittal plane deformity: an overview of interpretation and management. *Eur Spine J*. 2010;19:1824–36.
15. Diméglio A. Growth in pediatric orthopaedics. *J Pediatr Orthop*. 2001;21:549–5.
16. Diméglio A, Canavese F, Charles YP. Growth and adolescent idiopathic scoliosis: when and how much? *J Pediatr Orthop*. 2011;31(suppl):S28–36.
17. Kruschke JK. *Doing Bayesian data analysis A tutorial with R, JAGS and Stan*. Amsterdam: Academic Press2nd ed. 2015.
18. Pesenti S, Lafage R, Stein D, et al. The amount of proximal lumbar lordosis is related to pelvic incidence. *Clin Orthop Relat Res*. 2018;476:1603–1.
19. Vaz G, Roussouly P, Berthonnaud E, Dimnet J. Sagittal morphology and equilibrium of pelvis and spine. *Eur Spine J*. 2002;11:80–7.
20. Sullivan TB, Marino N, Reighard FG, Newton PO. Relationship between lumbar lordosis and pelvic incidence in the adolescent patient: normal cohort analysis and literature comparison. *Spine Deform*. 2018;6:529–36.
21. Abelin-Genevois K, Idjerouidene A, Roussouly P, et al. Cervical spine alignment in the pediatric population: a radiographic normative study of 150 asymptomatic patients. *Eur Spine J*. 2014;23:1442–8.
22. Hou C, Chen K, Chen Y, Zhou T, Yang M, Li M. Assessment of sagittal spinopelvic alignment in asymptomatic Chinese juveniles and adolescents: a large cohort study and comparative meta-analysis. *J Orthop Surg Res*. 2021;16:656.
23. Wang W, Wang Z, Liu Z, et al. Are there gender differences in sagittal spinal pelvic inclination before and after the adolescent pubertal growth spurt? *Eur Spine J*. 2015;24: 1168–74.
24. Mac-Thiong JM, Labelle H, Berthonnaud E, et al. Sagittal spinopelvic balance in normal children and adolescents. *Eur Spine J*. 2007;16:227–34.
25. Ghandhari H, Hesarikia H, Ameri E, Noori A. Assessment of normal sagittal alignment of the spine and pelvis in children and adolescents. *Biomed Res Int*. 2013;2013:842624.